Chapter 2
Data Needs and Hydrologic Processes of Floods

2-1. Overview

a. Hydrologic cycle. Water occurs on, in, and over the surface of the earth in many places, forms, and phases. The transformation from one phase to another and motion from one location to another are referred to as the hydrologic cycle. Major elements of the hydrologic cycle are shown in Figure 2-1.

b. Runoff. The process may be conceptualized as starting with precipitation occurring on the land surface. A portion of the precipitation is lost to evapotranspiration, infiltration, depression storage, and interception. The portion that is not lost becomes precipitation excess or runoff as:

Precipitation - Losses = Precipitation excess or runoff

c. Drainage systems. The surface runoff enters small hillside gullies and ditches, flows to brooks and creeks, and then to rivers that flow into the oceans. These systems, as shown by Figure 2-2, consist of a network of flow conveyance channels that occupy the lowest part of the landscape. The ridge of the land surface, or rim separating runoff networks, is called the drainage divide. The area of the land that encloses the divide may be referred to as the drainage area, watershed, or catchment of the stream.

d. Runoff hydrograph. The runoff from the watershed that occurs over time at the watershed outlet is a runoff hydrograph. Figure 2-3 shows a runoff hydrograph from a watershed with ordinates of discharge versus time. The runoff hydrograph enters the main stream channel, is added to the base flow (flow existing without the rainfall excess occurring) in the channel, and is combined with other runoff hydrographs as it is translated through the main stream system. The translation of the combined hydrographs through the stream system is also called flood routing.

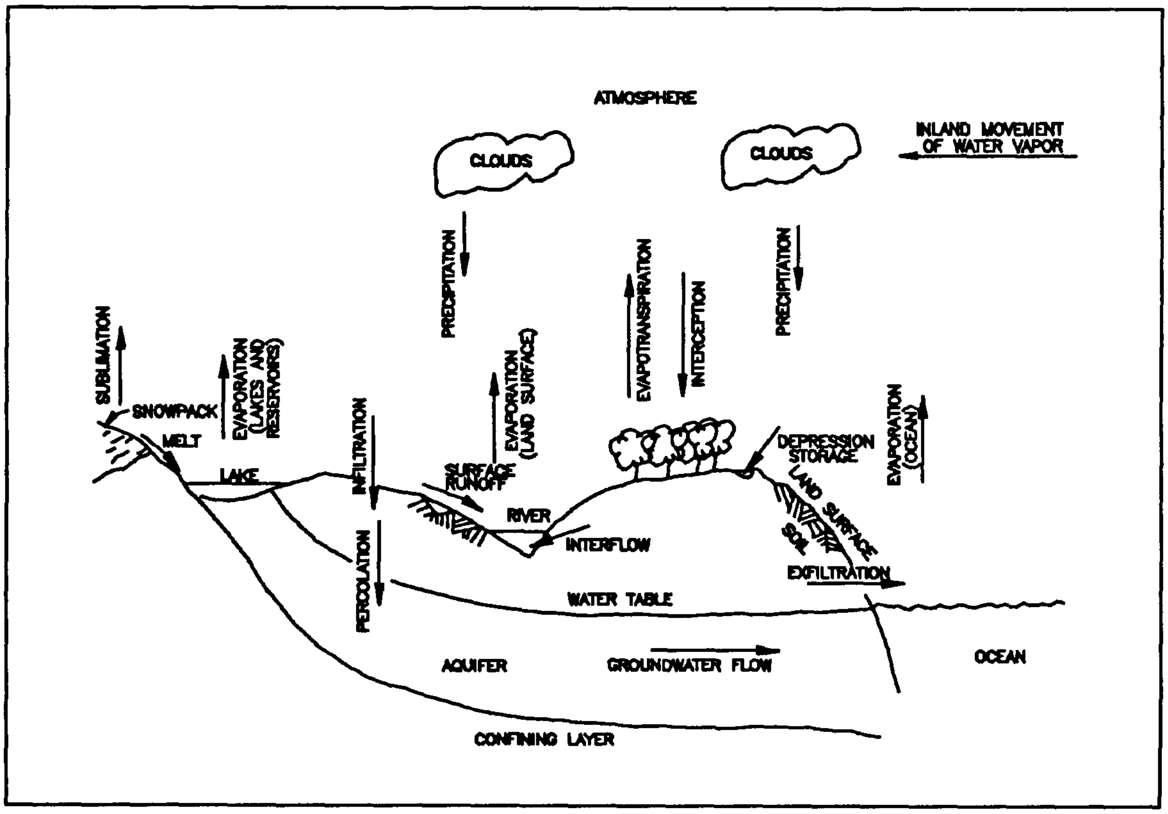

Figure 2-1. The hydrologic cycle

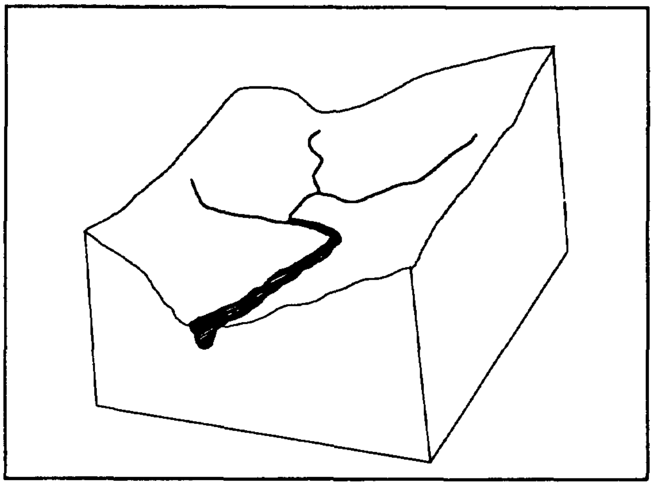

Figure 2-2. Drainage basin

e. Organization. The primary interests are the peak hydrograph discharge, the corresponding water level reached in the channel and overbank, and the frequency with which specific stages are reached. Paragraph 2-2 concentrates on developing the hydrograph and peak discharge, paragraphs 2-3 and 2-4 on water level determination, and paragraph 2-5 on frequency analysis.

2-2. Precipitation Runoff Relationship

a. Precipitation. Precipitation is derived from atmospheric moisture, resulting primarily from evaporation from the ocean. The predominate forms of precipitation are rain and snow, with hail, fog, drizzle, sleet, etc. being less important. The form of precipitation at the earth's surface is influenced by other climatic factors such as wind, temperature, atmospheric pressure, and humidity. Geographic factors such as latitude, altitude, topography, and location of land and water surfaces also influence the nature and amount of precipitation. The primary form of precipitation that causes runoff and flooding is rainfall, with melting snow also a contributor in some regions. Spatial extent, time variations, and intensity are important factors contributing to the runoff process. Areal distribution of precipitation is important and is highly correlated to the time history of runoff.

(1) Rainfall measurement. Rainfall intensities are measured by rain gages, which are either manually read or mechanically recorded. Manual gages are relatively inexpensive to install and read; however, rainfall information is normally available only in 24-hr increments. For most watersheds, rainfall intervals of less than 24 hr are necessary to adequately define the rainfall effects on the runoff hydrograph. Automated recorders are considerably more expensive, but can give rainfall intensities for increments as small as 5 minutes, necessary for small urban catchments. Figure 2-4 shows an automated precipitation recording gage. The National Weather Service (NWS) maintains a network of both types of gages throughout the United States; however, this network often has only limited data for a specific watershed. Small, urban watersheds may require the installation of one or more rainfall recorders to give site-specific information for a study area.

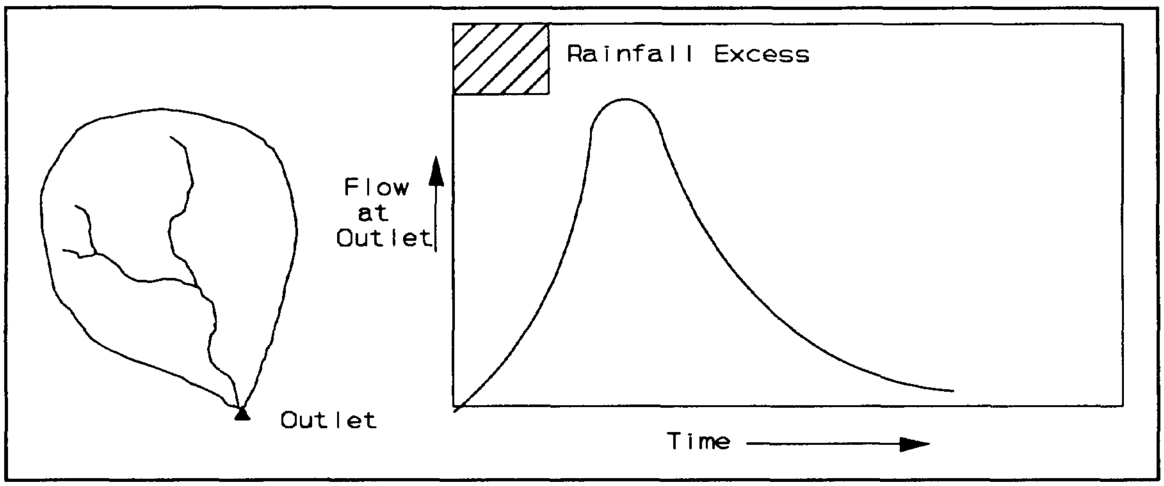

Figure 2-3. Runoff hydrograph

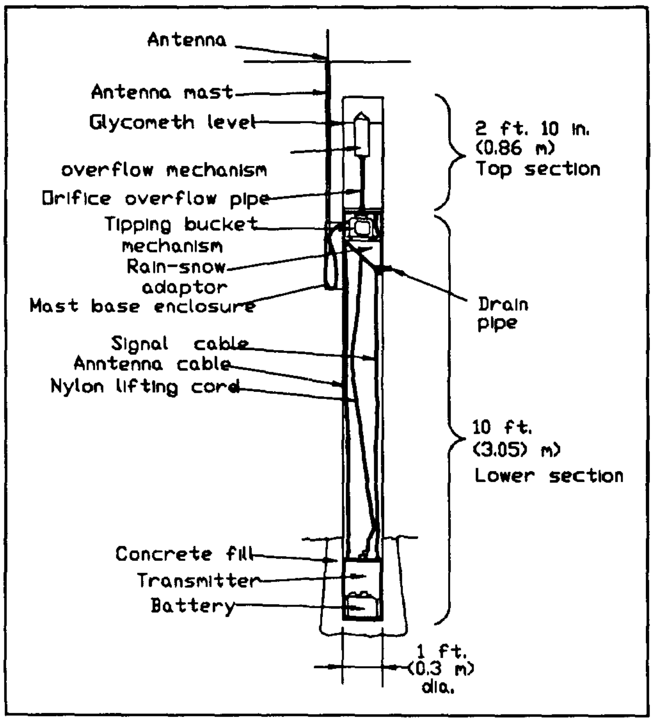

Figure 2-4. Automated rain gage

(2) Snowpack measurement.

(a) Snowfall is that part of precipitation which occurs as ice crystals. The aerial extent, water equivalent, depth of the snowpack, and how fast it melts contribute to the runoff process. The influence of snowfall on flooding is more important in northern and mountainous climates than in other sections of the United States.

(b) The snowpack depth is measured either manually, or by automated means. Manual measurement usually involves catching the snowfall in a cylinder, or cutting a sample from the snowpack, and then melting the collected snow for equivalent water content. Automated means can be used in remote areas and often consist of a "pillow" which records the increasing weight of the pack with time. Air temperature at the snowpack's surface is also necessary to predict the rate of melting, and the corresponding water excess to the streams.

b. Losses. Losses to precipitation falling on the earth and runoff into stream channels include evapotranspiration (evaporation from the ground surface and through foliage), depression storage (surface irregularities or "puddles"), interception (rainfall coating foliage), and infiltration (movement or transmission of surface water into the soil). Losses from evapotranspiration for flood events are generally considered negligible. Interception and depression storage losses depend on the surface topography and foliage of the system, but remain somewhat constant from event to event. Infiltration is the dominant source of losses during a flood event.

(1) Infiltration.

(a) Infiltration is a complex process involving the conceptual sequences of surface entry, transmission or percolation through the soil, and depletion of storage capacity of the soil. The infiltration rate decreases as the soil becomes saturated, thus resulting in greater runoff. Infiltration capacity can also significantly change over time due to development effects on the land surface.

(b) The major factors affecting infiltration are antecedent moisture conditions, land cover, and soil type. Soils and land use cover vary spatially over the watershed, whereas antecedent moisture conditions vary from event to event. Land use cover may also vary seasonally (vegetal cover) or over a period of time (urbanization). Information on soil type and land use is collected to aid in the estimate of infiltration losses.

(c) The effects of antecedent moisture conditions, soil type, and land use cover are conceptually depicted by Figure 2-5. The buckets represent the storage capacity of the soil, which becomes smaller when saturated, as shown by Figure 2-5a. In Figure 2-5b, the soil characteristics were changed to demonstrate the transmission variability of different soils. In Figure 2-5c, the surface entry of the soil has been reduced because of urbanization (imperviousness) of the land surface (USACE 1981).

(2) Infiltration measurement. Although many attempts have been made to measure losses directly, only limited success has been achieved. Losses on a specific watershed are usually inferred by measuring basin average rainfall using one or more gages (input to the basin), measuring the runoff hydrograph at a stream gage (output from the basin, or rainfall excess), and determining losses by subtracting rainfall excess from the rainfall. These losses could be distributed over the time of the storm, determining an average loss per time period to use for other rainfall events for which no discharge data are available.

c. Discharge hydrographs. Discharge hydrographs are generally considered to have two parts, direct runoff and base flow. Direct runoff is the rainfall excess received from recent storm runoff, while base, or groundwater, flow occurs regardless of the storm runoff. Base

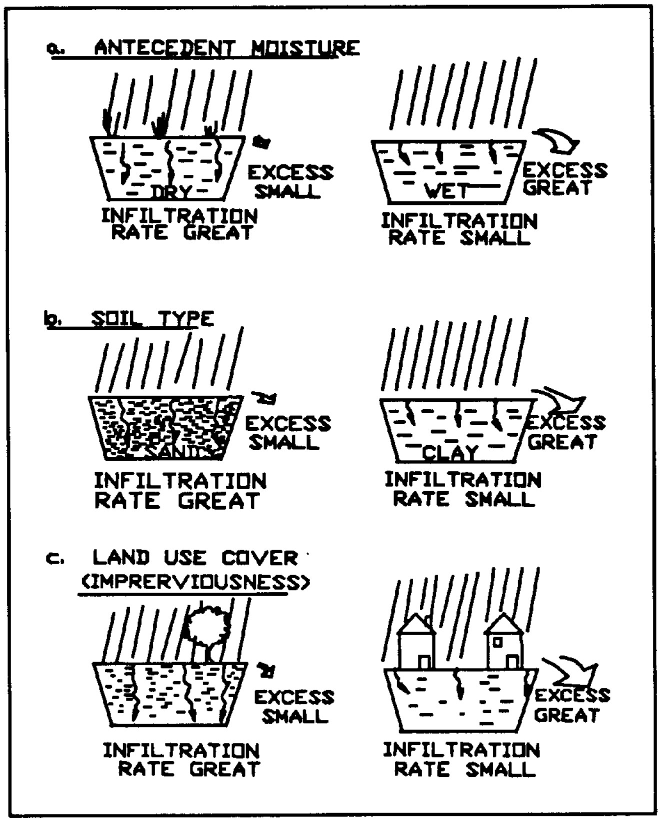

Figure 2-5. Infiltration losses

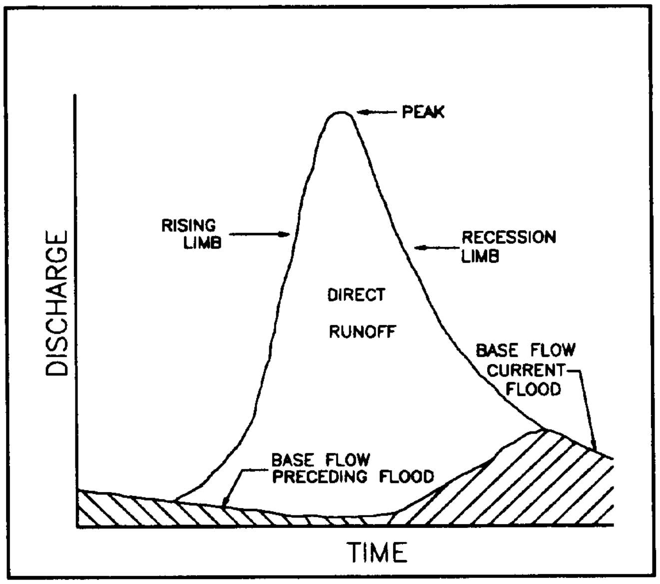

Figure 2-6. Discharge hydrograph features

flow is a relatively small part of the overall hydrograph and is important primarily on large watersheds. Base flow and direct runoff are shown on Figure 2-6. Hydrograph characteristics such as peak discharge, time to peak, and volume of runoff are based on the shape of the hydrograph. In turn, the shape is dependent on precipitation patterns, losses, and basin characteristics.

(1) Intensity patterns. Time-intensity patterns of rainfall excess can have a significant effect on the peak, shape, and duration of the hydrograph. Figure 2-7 shows examples of the effects of various intensity patterns. Changes in storm intensity must last for hours or days to cause distinguishable effects on the hydrograph for a large watershed. For small basins, clearly defined peaks in the hydrographs may be caused by a few minutes of intense rainfall excess.

(2) Characteristics affecting hydrograph. Precipitation affects runoff directly only if the physical characteristics of the watershed are relatively constant. However, these characteristics are often not uniform within a

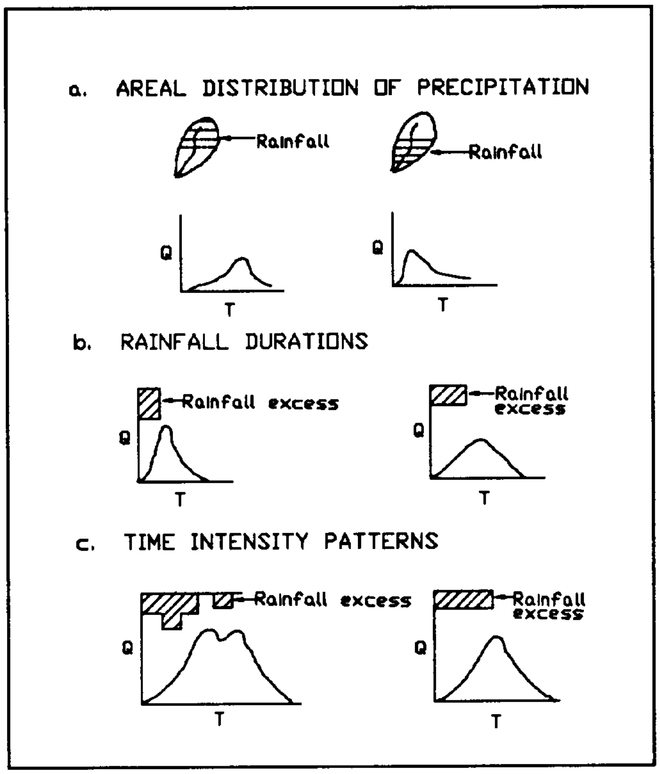

Figure 2-7. Rainfall characteristic effects on runoff hydrographs

watershed or between watersheds. Basin characteristics affecting the hydrograph include:

- Size of the watershed.
- Shape of the watershed.
- Length of the main channel.
- Land and channel slopes.
- Roughness of land and channels.
- Drainage density.
- Valley storage.

(3) Effects of physical characteristics. The effects of the physical characteristics of a watershed on the runoff hydrograph are conceptualized in Figures 2-8 and 2-9. As the runoff enters the main channels, the volume, shape, peak flow, and timing all affect the magnitude of flow. These characteristics are defined primarily through field reconnaissance and map analysis.

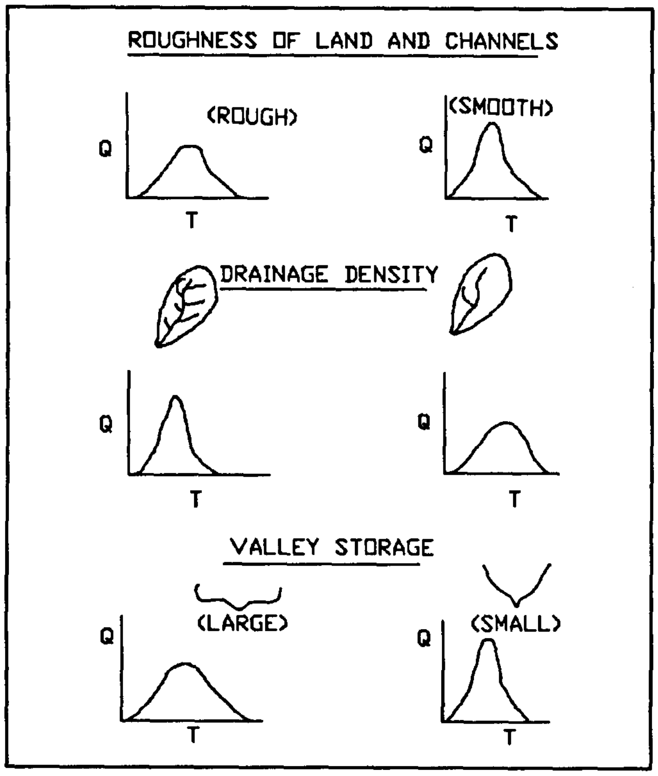

Figure 2-8. Effects of basin characteristics on runoff hydrographs

d. Hydrograph measurements.

(1) Stream gages. Runoff hydrographs and direct runoff from a storm may be determined directly by measurement at a stream gage. A stream gage could be as

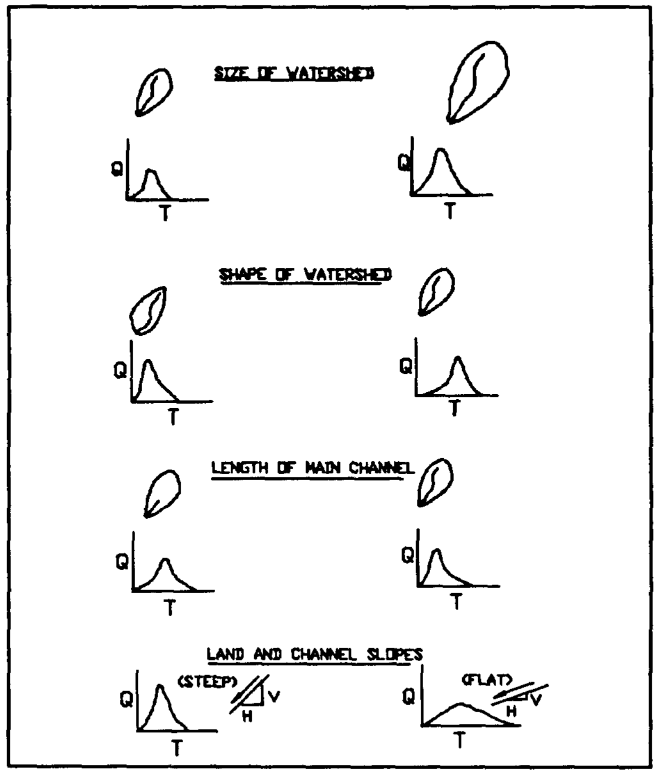

Figure 2-9. Additional effects of basin characteristic on runoff hydrographs

simple as a graduated board read once a day, or as sophisticated as an automated gage recording in 5-minute intervals and reporting by satellite telemetry. The cost of these installations varies significantly.

(2) Recorders. A manual recorder is quite inexpensive, but gives only stage, or water level readings, usually once per day. These gage records produce a stage hydrograph, but no information on discharge. A continuous recorder measures water level at predetermined intervals, providing a continuous trace of water level changes. Water levels are converted to discharge by periodic physical measurements of the stream cross-sectional area and river velocity, made with current meters. These discharge measurements are made once a week to once a month for normal flows, and as often as possible during floods. Over time, these measurements can define a relationship between water level and discharge, allowing one to estimate discharge based on the water level.

(3) Gage installation. Because of the expense, stream gages are not as numerous as one might wish. When no gages exist in the study watershed, it may be necessary to install one or more for a limited data

collection program. This activity must be accomplished well in advance of the hydrologic analysis and other general study activities. These data are supplemented with additional information derived by methods discussed in later chapters.

2-3. Channel Characteristics

a. General.

(1) Channel systems. Most streams flow within a channel system bordered on one or both sides by a relatively flat area called a valley or floodplain. For in-channel flow, the velocity is less nearer the bottom and sides than it is nearer the center and surface due to boundary friction. For straight channel reaches with relatively constant dimensions, the flow approaches one-dimensional flow in the downstream direction. Channel bed deposition and scour occur depending on channel slope, bed material, and velocity of flow.

(2) Flow patterns. Channels, however, are seldom straight for long reaches, and channel bends and curves have an important effect on the flow. As the stream enters the bend, the flow near the surface tends to move towards the concave bank and the flow near the bottom moves toward the convex bank, as shown in Figure 2-10. This flow pattern results in erosion on the concave (outside) side of the bend and deposition on the convex (inside) side of the bend. The flow pattern is somewhat spiral-shaped, or three-dimensional, in its movement.

(3) Meandering. The stream is thus constantly moving laterally or meandering in its natural state, with deposition occurring on one side and erosion on the other. Meandering occurs slowly during normal flows, with the rate increasing considerably during floods. This process, plus overbank deposition of sediments during floods, creates the floodplain shown in Figure 2-11.

(4) Alteration of flow patterns. In addition to bends, other alterations to flow patterns are caused by changes in flow, in the cross-sectional geometry of the channel area, and in the boundary roughness of the channel area. These alterations can cause eddies, backwaters, drawdowns, and jumps. Changes in cross-sectional areas may result from expansions, contractions, and obstructions to the flow area. For flow within banks, these changes may occur naturally, or from obstructions, such as boulders and debris. The changes may also result from man's channel construction, bridges, pipeline crossings, and numerous other modifications.

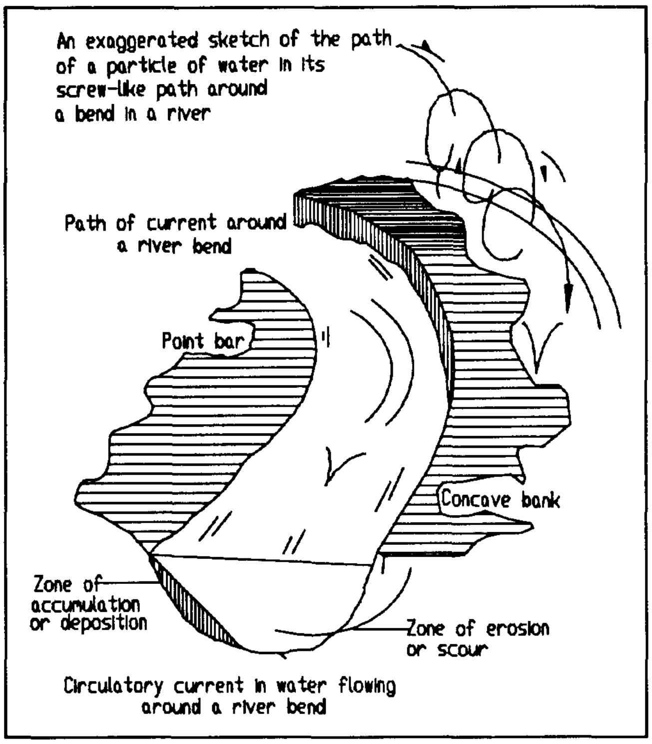

Figure 2-10. Channel flow patterns

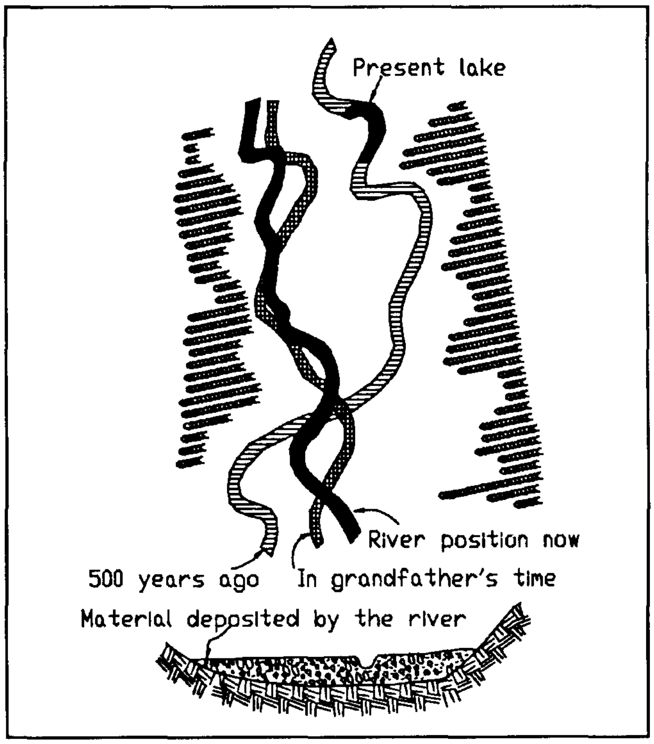

Figure 2-11. Floodplain development concepts

(5) Channel capacity. All of these physical effects result in a specific capacity for the channel, which can vary somewhat along the reach of the stream. Channel capacity is an important variable. Typically, damage occurs when the channel flow capacity is exceeded.

b. Field measurements.

(1) General. Measurements of stage and discharge have been previously discussed in paragraph 2-2*c*. Changes in flow patterns are largely determined from field surveys of the channel and overbank geometry throughout the study reach. The location of survey data is based on examination of the stream reach and determining where significant changes in channel and overbank geometry occur. Bridge obstructions are particularly significant.

(2) Sedimentation. Where sedimentation is important, measurements of sediment flow as well as water discharge are needed. Data collection and analysis at sediment sampling sites are expensive, but necessary to address the existing sediment regime and how various flood damage reduction projects may affect it. Suspended sediment samples are collected at a discharge site at similar intervals as discharge measurements. Over time, these measurements produce a relationship of water discharge to sediment discharge, so that knowledge of the stage can allow estimates of both water and suspended sediment discharge. An estimate of sediment moving along the bed of the stream (bed load, or unmeasured load) is also necessary for complete definition of the sediment load for a given discharge.

2-4. Flood Characteristics

a. General. Flooding is a natural characteristic of a stream system and can be considered an overbank flow. It occurs when water in the stream system exceeds the channel capacity, causing an overflow onto the valley or floodplain. Flood damage is the destruction or loss of property caused by water that cannot be carried within the normal channel. Flooding is usually the result of rainfall excess or snowmelt, but occasionally can be from failure of engineered structures.

b. Flow characteristics. As the flood hydrograph moves through the stream system, effects on flow characteristics can be dramatic. High velocities in the channel may cause bank erosion and scour to the bed, increasing the sediment load, which is subsequently deposited in areas of slower velocities, such as the floodplain. Severe floods have produced major changes in channel and overbank characteristics.

c. Movement of flood hydrograph. The movement of the flood hydrograph through the stream system affects the hydrograph shape due to the travel time of the flood and to the natural storage in the floodplain, or to man-made storage such as in reservoirs. As the flood waters increase in height and flow into the overbank areas occurs, the storage in the overbanks tends to delay and reduce the peak as shown in Figure 2-12.

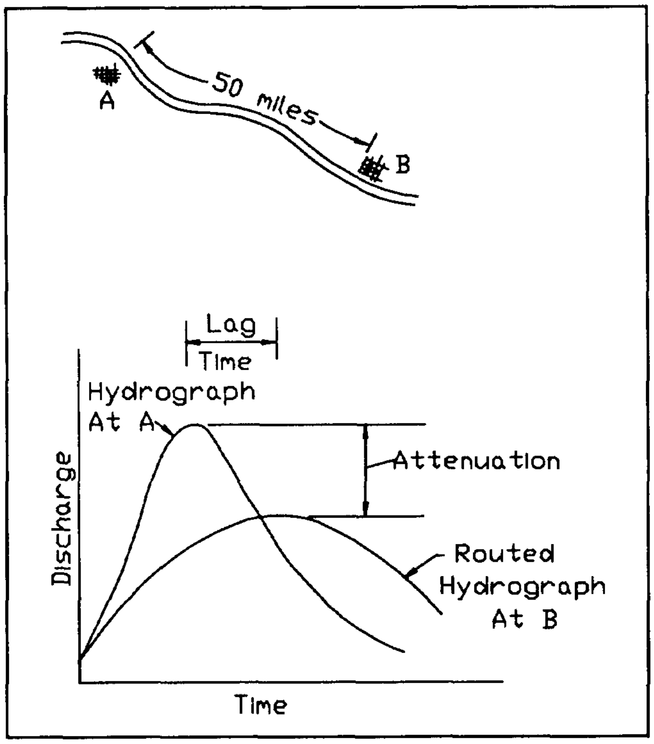

Figure 2-12. Effects of flood hydrograph translation

d. Analysis requirements. Analysis of flood movement or routing may include the determination of the peak stage or elevation at all key points. Usually peak stages are determined separately through river hydraulic studies. Hydrology, therefore, normally encompasses the development of surface water runoff, hydrograph combination, and routing to determine peak discharges at all key locations. Hydraulic analysis for flood damage reduction studies utilizes these discharges to determine the peak water surface elevation. How often the flood occurs (frequency) must then be determined.

2-5. Frequency Analysis

a. General. Frequency forms the third primary analysis requirement, along with water level and discharge. The determination of economic benefits of a project requires a knowledge of how often flooding occurs at various flood levels. This requirement is met through the analysis of stage- or discharge-frequency curves for conditions of interest.

b. Methods of analysis. This analysis may be developed by statistical methods if a long-term hydrologic record exists at a stream gage in the study reach. Typically, however, long-record data are scarce for most hydrologic analyses. Even if such a record is present, other locations, having limited data, also must be evaluated for frequency. Therefore, frequency determinations usually consist of the application of hypothetical storms of specified frequency (10-, 2-, and 1-percent annual chance exceedance, etc.) to a hydrologic model of the watershed to determine discharge-frequency relationships at all desired locations.

c. Hydrologic models. Hydrologic models are often calibrated so that observed rainfall frequency approximately corresponds to discharge frequency. Loss rates are usually adjusted, based on judgement, to reflect the severity of the hypothetical floods.